USING FOSSIL FUEL COMBUSTION PRODUCTS TO REDUCE ACID MINE DRAINAGE SLUDGE VOLUMES

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Abstract

This study evaluated the use of regionally produced coal combustion products to neutralize and remove metals from acid mine drainage (AMD). Synthetic AMD mixtures were treated with a number of fly ashes and fluidized bed combustion (FBC) ashes. All of the ashes reduced the volume of the sludge produced and gave a faster settling rate than the sludge produced by treatment with lime. Faster settling allows greater throughput rates. In addition, the FBC ashes, which generally contain alkaline components used for sulfur capture, completely neutralized the acidity and, if desired, raised the pH above 10. The fly ashes, on the other hand, reduced the final volume of sludge, but required additional neutralizing agents to attain a pH above 5. The pH of the AMD can be taken to above 10 to insure complete removal of manganese, or it can be taken to a more neutral pH of 7 or 8 for safe introduction of the aqueous phase into ponds or streams. The process combines two industrial waste products in order to reduce the disposal volume of one of the waste products and to produce an environmentally safe aqueous discharge.

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Background

At many sites the extraction of minerals, including coal, produces water with a high metals content, often accompanied by excessive acidity. The method of choice for the remediation of acidic drainage from thousands of bituminous coal mines in Appalachia, the Midwest, and elsewhere is alkaline addition. The alkaline treatments include the use of lime, limestone, caustic solutions, and ammonia (Brown, et al., 1996). Raising the pH by the use of these treatments results in the removal of iron, aluminum, manganese and other metals from mine water before the water is discharged into large rivers, reservoirs, and aquifers. The resultant product of such metal removal is a colloidal precipitate, or sludge, which is commonly collectedin settling ponds and ultimately requires disposal. The area of land necessary for settling ponds depends not only on the flow rate of the treated water, but also on how fast the sludge will settle, and dewater. The cost associated with the transport of sludge to a disposal site depends on the amount of residual water in the sludge and can be many times the cost of the treatment chemicals (Phipps, et al., 1996).

Even after months of settling, these sludges may contain more than 75% water. The real estate required for settling ponds and the cost of future transport of the sludge would be greatly reduced by the prior application of an effective dewatering method. Rapid settling would also increase the effective throughput rate for water treatment. Finally, greater ultimate sludge density (solids content) would lower transportation costs to utilization or disposal sites and increase the likelihood of utilization.

Typical treatment processes are designed to raise the pH of the effluent to within the range of 6.0 to 9.0 and reduce the total iron concentration to less than three ppm. However, in meeting these effluent standards, large volumes of iron hydroxide sludge are produced. Federal laws require treatment of acid mine drainage as long as the acid conditions exist (CFR, 1999); therefore, sludge production will continue as long as the water must be treated, even though mining operations have ceased. Thus, solving one problem has generated another -- the disposal of the AMD treatment sludge. The disposal of the water treatment waste is a serious problem because of the voluminuous nature of the sludge, and because of the enormous amounts of iron hydroxide sludge produced annually.

Coal ash is the primary component of solid fossil fuel combustion residues from coal burning power plants. These residues can include combustion products such as fly ash, bottom ash, flue gas desulfurization sludge (FGDS), and fluidized bed combustion (FBC) waste. Coal burning power plants generate most of the electricity in the U.S. and produce millions of metric tons of ash annually. The percentage derived from FBC technology is expected to increase to address requirements of the Clean Air Act. The higher carbon content of FBC ash hinders its utilization as a component in concrete (Knoll and Behr-Andres, 1998). Approximately 70% of the coal ash is disposed of in landfills and surface impoundments. With shrinking landfill space and an increasing percentage of ash being generated that is less desirable to the construction industry, there is an urgent need to utilize these materials in a beneficial and environmentally safe manner.

A technique, which utilizes quantities of FBC ash to reduce the volume of sludge produced from AMD, and which gives a rapid settling and dewatering of the sludge, would appear to be of significant benefit. It would (1) reduce the costs of storing and moving sludge, (2) reduce the costs of water treatment, (3) provide an environmentally safe aqueous phase, and (4) reduce the amount of land needed for sludge storage and disposal.

Experimental

EQUIPMENT

The pH meter used in all experiments was a Corning Model 240. (Reference to any specific commercial product by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof.)

The Imhoff cones were Wheaton 1000ml Stryene-Acrylonitrile cones.

CHEMICALS

Calcium hydroxide was Fisher Certified ACS. The sodium hydroxide was Fisher Certified ACS 10N diluted to 1N.   The synthetic AMD was made from the following salts:

Ferrous Sulfate - Fisher ACS, Aluminum Sulfate - Fisher ACS, Ferric Sulfate - Mallinckrodt Reagent Grade, Zinc Sulfate - Fisher ACS, Manganous Sulfate - Fisher ACS

ASHES

The ashes used in the study were obtained from various sources. It is not necessary, in the context of this study, to identify the specific sites that produced the ashes. The elemental analysis of the ashes used is shown in Table 1. The FBC process uses additives, such as limestone and dolomite ($CaCO_3$ and $(CaMg)CO_3$), to remove sulfur from flue gas. Lime, produced during combustion, gives the FBC ashes much greater neutralizing capacity than the non-FBC ashes. It was possible, with the FBC ashes, to raise the pH of the AMD to above 10. Most of the fly ashes tested did not raise the AMD above a pH of 5. All of these ashes are, of course, not homogeneous, which leads to an inability to achieve exactly reproducible results from one test to the next.

TITRATION CURVES

Figures 1,2,3 and 4 show the titration pH curves for the neutralization of the synthetic AMD using NaOH, $Ca(OH)_2$, and FBC ashes. Incremental amounts of the neutralization materials were added. The NaOH used in the titration was 1.0N. A 0.5<u>M</u> $Ca(OH)_2$ slurry was utilized. The slurry was continually stirred during the addition process. NaOH and $Ca(OH)_2$ were added by injection by pipet, while the ashes were added by incremental weight. All the curves are similar, with the NaOH showing the most rapid neutralization rate.

PERCENT SOLIDS

To determine the percent solids, the sludges were initially allowed to settle in the Imhoff cones for 20 hours. The contents of the cone were then gravity filtered through #4 filter paper. The wet sludge was allowed to remain on the filter paper until no additional aqueous filtrate was noted dropping from the paper. The wet sludge was scraped from the filter paper into a preweighed Petrie dish, and the wet sludge was weighed. The sludge was then dried in an oven for 24 hours at 110 degrees centigrade. The dry sludge was then weighed, and the weight of the dry sludge was compared to the weight of the wet sludge.

AMD COMPOSITION

A synthetic AMD mixture was used in all experiments. The same solution composition was used for each experiment in order to provide a legitimate comparison of all phases of the work. The AMD standard solution was made from the sulfate salts of five of the major components of concern in actual AMD. The five components were ferric iron, ferrous iron, aluminum, zinc, and manganese. Table 2 shows the synthetic AMD composition. The concentrations of both Mn^{+2} and Zn^{+2} were intentionally set at a relatively high 50ppm in the standard to facilitate weighing and analysis.

Table 3 shows the average concentrations of the same five metals for AMD taken at the treatment inlet at Omega mine over a twelve-month period. The concentrations of the various species in the AMD at the Omega mine site, near Morgantown, WV are shown for comparison and vary with changes in precipitation at the mine and with changes in the AMD remediation process.

Table 4 is a complete analysis of Omega AMD from a typical sampling event. This analysis is from samples of untreated water taken at the treatment inlet.

The AMD from Omega mine appears to be typical of the AMD produced at many coal mines. Table 5 is data compiled from the water analysis from 128 AMD discharges (Hyman and Watzlaf, 1996). These sources included active, reclaimed, and abandoned surface and underground mines as well as coal waste materials. Samples from the states of PA, WV, OH, TN, MD, MT, KY, CO, OK, and MO are included. Note the wide range of values in the minimum and maximum columns.

Results and discussion

TITRATION CURVES

Titration curves were developed for all the reagents used in the study, including NaOH, lime and the various ashes. These curves are important because, from them, one can determine the pH at which the various metals precipitate from an AMD solution. Figure 1 is the titration curve of the neutralization of the synthetic AMD with 1.0N NaOH. The vertical sections of the curve are the areas where a significant change in pH is occurring with addition of neutralizing agent. The horizontal sections, on the other hand, are areas where the pH is changing very little or not at all, by addition of neutralizing agent. This latter behavior indicates that the neutralizing agent is being used to generate salts of the metals, rather than raising the pH of the solution.

The NaOH neutralization in Fig. 1 could be considered the ideal because the NaOH is in solution and can react quickly and completely. The first horizontal or flat area of the curve is associated with the precipitation of ferric iron, while the second flat section is due to the precipitation of aluminum and zinc. The third horizontal section is due to the precipitation of the remaining metals in the synthetic AMD - ferrous iron and manganese, with ferrous reactions primarily in the lower pH, and manganese in the higher pH portions of this plateau. After this precipitation, the curve rises rapidly, indicating that little further precipitation is taking place.

The curve shown in Fig. 2 for the neutralization using 0.5M lime slurry is very similar to Fig. 1. All the metals precipitate out at the same points on the curve.

Figures 3 and 4 are the curves for the neutralization with two FBC ashes. The most important aspect illustrated in these plots is that both FBC ashes have the neutralizing capacity to reach a pH high enough to precipitate all the metals in the synthetic AMD. The vertical and horizontal areas of these curves are not as well defined as those produced by the lime and NaOH, and may be due to a number of factors. The ashes are particulate in nature and not completely soluble in the AMD. This limited solubility could also be relatively slow, which would lead to a slower neutralization rate. Another factor is that these ashes are complex entities, composed of a number of components, which will react to varying degrees and rates with the AMD. The ashes are certainly nonhomogeneous materials. All these factors could contribute to the blurring of the more distinct vertical and horizontal sections of the titrations with lime and NaOH.

SLUDGE REDUCTION WITH FBC ASH

The synthetic AMD was prepared in a beaker with a stirring bar. A measured 500 mL quantity of deionized water was added. This mixture was then magnetically stirred and the pH was monitored while the neutralizing agent was added incrementally. After the desired pH was reached and metal precipitation was complete, the generated sludge was poured into an Imhoff cone, and the rate and degree of settling in the cone was monitored. The final reading of the settled volume was taken in approximately 20 hours, thus concluding the experiment. The sludge was then gravity filtered in order to determine the percent solids.

This part of the study consisted of comparing the rates of settling and the final volumes of the sludges formed by neutralization of the AMD with lime and FBC ashes. Two FBC ashes (ME and FA34) were utilized in this study. The results from these tests and the subsequent experiments with fly ashes are shown in Table 6. The results of the lime neutralization are plotted in Fig. 5. The top curve shows the behavior of the lime sludge neutralized to a pH of 10, while the lower curve is for the lime sludge neutralized to a pH of 8. At the end of four hours, the final volume of the lime sludges had not yet been reached. The volume of lime sludges neutralized to a pH of 10 averaged 129 mL in the cone. The volumes of the lime sludges taken to a pH of 8 averaged 96 mL. When the lime slurry was taken through the same experimental procedure without AMD present, the final volume of the settled lime in the cone averaged about 2.5 mL. This result is represented by the almost horizontal line of the lowest plot. The quantity of lime slurry used in this experiment when no AMD was present was an average of the amounts added during the AMD neutralization. This indicates that most of the volume in these experiments was due to the sludge which formed. Figure 5 shows this graphically.

Table 6 and Figs. 6 and 7 show the results of the neutralization experiments with FBC ashes. Two different ashes (ME and FA34) were used, and both gave similar results. Each plot shows the behavior from different experimental conditions. The ash was added to the AMD and the pH taken to 10 in one series, and to pH 8 in another series of experiments. Then, in separate experiments, the same amount of ash was added to water with no AMD as had been used to take the synthetic AMD to pH values of 10 and 8. Figure 6 shows the results from the ME FBC ash, while Fig. 7 represents the FA34 FBC ash. From the plots is can be seen that the final settling volume was reached in about one hour for both ashes. This final volume averaged 44 mL for the ME FBC ash and 34 mL for the FA34 FBC ash, when the neutralization was stopped at pH 10. At pH 8, the final volume for the first ash was 33 mL, while the volume of the second was 29 mL. When the ashes were run through the procedure without AMD present, the final volume of ash alone averaged 10 to 15 mL less in all cases. This finding means that the volume of the sludge formed by the FBC ash was only about 10 to 15 mL in volume, as opposed to the final volumes of over 100 mL that were formed by lime addition. Figures 8 and 9 show this graphically. Figure 8 compares the treatments at pH 8, while the comparison at pH 10 is shown in Fig. 9. These plots show the similar behavior of the two FBC ashes and the difference in the final volumes of sludge formed by the ashes when compared to the lime sludge. From the plots, it is also easy to see that the final settled volume of the sludge generated by the FBC ashes was reached in less than an hour, while the lime sludge had not reached its final settled volume in four hours.

SLUDGE REDUCTION WITH FLY ASH AND LIME SLURRY

The advantageous effects on AMD remediation sludge volume are not limited to FBC ash. (Hustwit, 1995). As depicted in Figs. 10 and 11, the addition of fly ash from pulverized coal combustion operations can suppress sludge volume relative to conventional hydrated lime treatment. None of the four non-FBC ashes used in this study had sufficient alkalinity to neutralize the synthetic AMD without the addition of other reagents. In Fig. 10, the first three legend symbols correspond to plots of data from 500 mL of simulated AMD treated with lime slurry to above pH 10, then stirred with 10g (sl, 10g), 25g (sl, 25g), or 50g (sl, 50g) of fly ash FA 4. The plot from the last of these three runs shows the highest sludge volume, which may be an indication of diminishing returns from the use of this large volume of ash material. Comparative plots are shown from runs in which 25g of FA 4 (25g, sl) or 50g (50g, sl) of this ash were first stirred with the AMD, and then sufficient lime slurry was added to bring the pH above 10. The addition of over 100g of FA 4 alone failed to bring the simulated AMD pH above 10. Still, the alkalinity of this ash meant that less lime slurry was required to raise the pH over 10 (20% and 40 % respectively) by this addition sequence. These latter plots indicate a lower sludge volume, especially for earlier settling times. The final plot is of settling behavior of this fly ash (18g) in deionized water without AMD salts as a volume baseline. In Fig. 11, the same symbolic representations in the legend refer to plots of similar runs with fly ash FA 13. Results from the use of other fly ashes, designated in our laboratory as FA 8 and FM 1, were similar to those of FA 13 and were omitted for brevity. The alkalinity of FA 13 was negligible. In the runs represented by this series of plots, the same amount of lime slurry was required to raise the AMD mix pH above 10 after stirring with ash as before, and there is also no significant difference in sludge settling behavior with respect to the sequence of ash addition. Nonetheless, there is a significant suppression of sludge volume relative to treatment with lime slurry alone. This suppression is nearly identical to that observed with 10g or 25g of FA 4 added to lime-generated sludge. This modest reduction in volume with low-alkaline fly ashes is unlikely in itself to drive its adoption as a process of choice in AMD treatment, since an accompanying process, such as lime addition is still needed to precipitate the contained metals.

PERCENT SOLIDS

A study by Green International (1976) found a "normal range of solids in mine drainage sludge of 1 to 6 percent, with 2.5 percent being a good average value." These numbers seem to agree with other reported studies (Zick et al., 1999; WVU, 1971; U.S. EPA, 1983). Table 7 shows that sludges formed from neutralizing the synthetic mine drainage with a 0.5M lime slurry gave an average percent solids number of 3.75%. This sludge would seem to fall into the normal range of solids in an AMD hydroxide sludge. When this same synthetic AMD was treated with either of the FBC ashes used in this study, the percent solids increased by a factor of 10 to over 40%. Both FBC ashes gave the same amount of solid sludge material. This means that much less water would be retained in sludges stored in ponds or other repositories. Much more sludge could therefore be stored, and much less water would be transported if the sludge was relocated.

TOXIC METAL RELEASE

Neutralization of the AMD with FBC ash provides a final solution with a pH that allows the aqueous phase to be directly discharged into streams and creeks. However, given the high concentrations of some metal species in the AMD, and in the ash, it is possible that utilizing this method would allow toxic levels of metals to be released into potable water supplies. A series of experiments was carried out to address this issue. The metal content of the ashes used in the study was first determined. After neutralization of the synthetic AMD mixture, both the solids and the aqueous phase produced by the neutralization were analyzed. The main objective was to determine how much of the metal content of the ashes and the AMD was partitioned to the final aqueous phase after precipitation, since this aqueous phase would ultimately be released to streams and creeks.

Results from Elemental Analyses

Ashes, sludges, and supernatant filtrates were analyzed for the following elements:

aluminum (Al)	cadmium (Cd)	magnesium (Mg)	silver (Ag)
arsenic (As)	chromium (Cr)	manganese (Mn)	sodium (Na)
antimony (Sb)	cobalt (Co)	molybdenum (Mo)	sulfur (S)
barium (Ba)	copper (Cu)	nickel (Ni)	thallium (Tl)
beryllium (Be)	iron (Fe)	potassium (K)	vanadium (V)
calcium (Ca)	lead (Pb)	selenium (Se)	zinc (Zn)

The results demonstrated that the treatments with FBC ashes or with hydrated lime slurry to pH 8 essentially removed the target metals Al, Fe, and Zn, while reducing the level of Mn to low ppm values. At pH 10, Mn was removed, but Al was resolublized to low ppm levels. The elements Sb, Se, Ag, and Tl were absent from all samples. Ash and lime treatments added Ca and to a lesser extent Mg, Na, and K to both solids and liquids of treated samples. The metals Mo, at 20-50 ppb, and Ba, at 50-100 ppb levels, were detected in ash treated supernatant layers. Other metals were detected in the ashes, and were carried into treated sludges, but were not released into the water layers.

Conclusions

1. The method demonstrates a way to combine two waste products, AMD sludge and coal combustion ash, to economically address a problem of the mining industry.

2. Acid mine drainage can be neutralized with FBC ash. No investment in lime or other neutralizing agent is required.

3. The addition of either fly ash or FBC ash reduces the volume of the resulting sludge to much less than that produced by adding lime to acid mine drainage.

4. Neutralization of AMD with FBC ash is much more advantageous than neutralization with conventional fly ash. Conventional fly ash does not have the neutralization capacity of the FBC ash. The fly ash can be used to reduce the volume of the sludge, but a neutralizing agent such as lime, ammonia, or limestone must be added to provide the capacity to bring the pH of the AMD to the basicity desired. The volume of neutralizing agent added somewhat negates the sludge reduction produced by the fly ash alone.

5. With addition of either FBC ash or fly ash, the sludge settles much more quickly than the settling rate produced by lime addition. This is important because it allows faster throughput of the sludge and allows the resulting aqueous phase to be discharged much more quickly from sludge ponds back into streams and creeks.

6. Neutralization by addition of FBC ash can be adjusted. A somewhat neutral pH of 7 or 8 can be used to provide an aqueous phase, which can then be discharged directly to a stream or creek or other potable water supply. A second option might be to raise the pH to 10 to remove metals such as manganese or ferrous iron.

7. AMD neutralization with FBC ash results in an aqueous phase that meets water quality standards with respect to trace metals and can be returned to the environment without further metal removal treatment.

FIG. 1

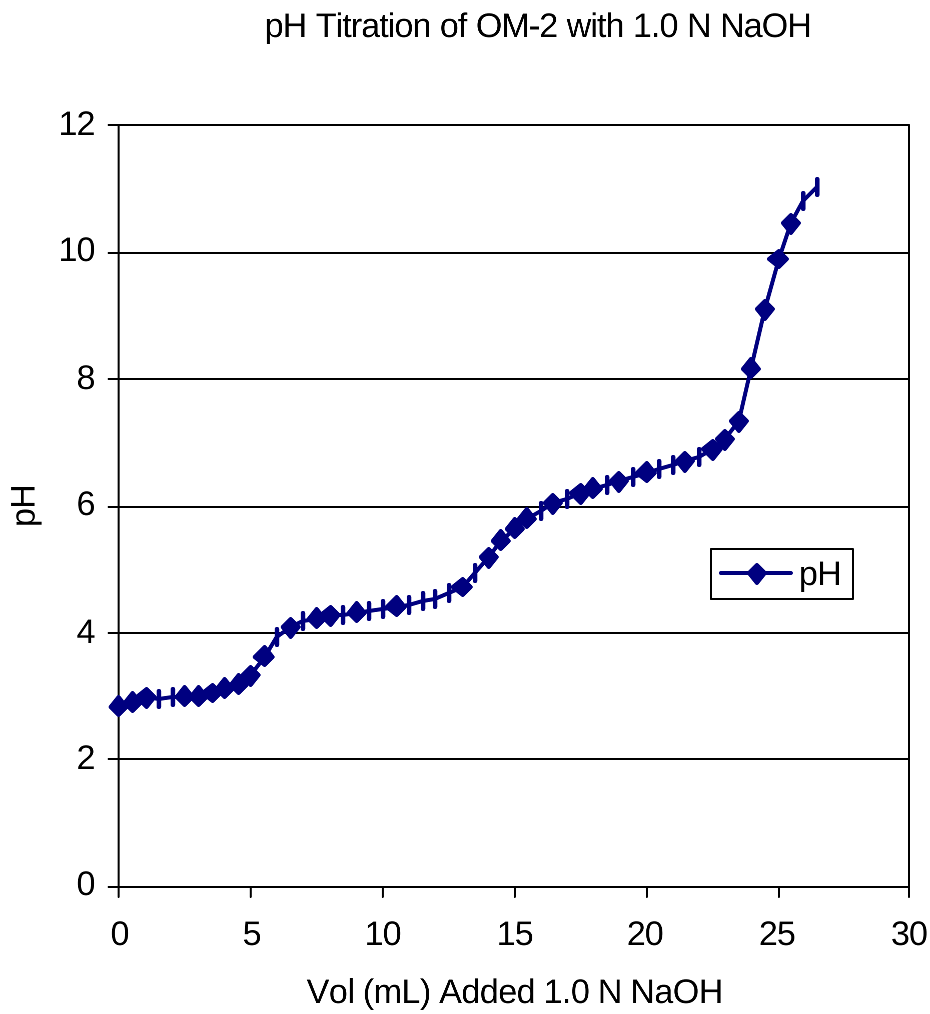
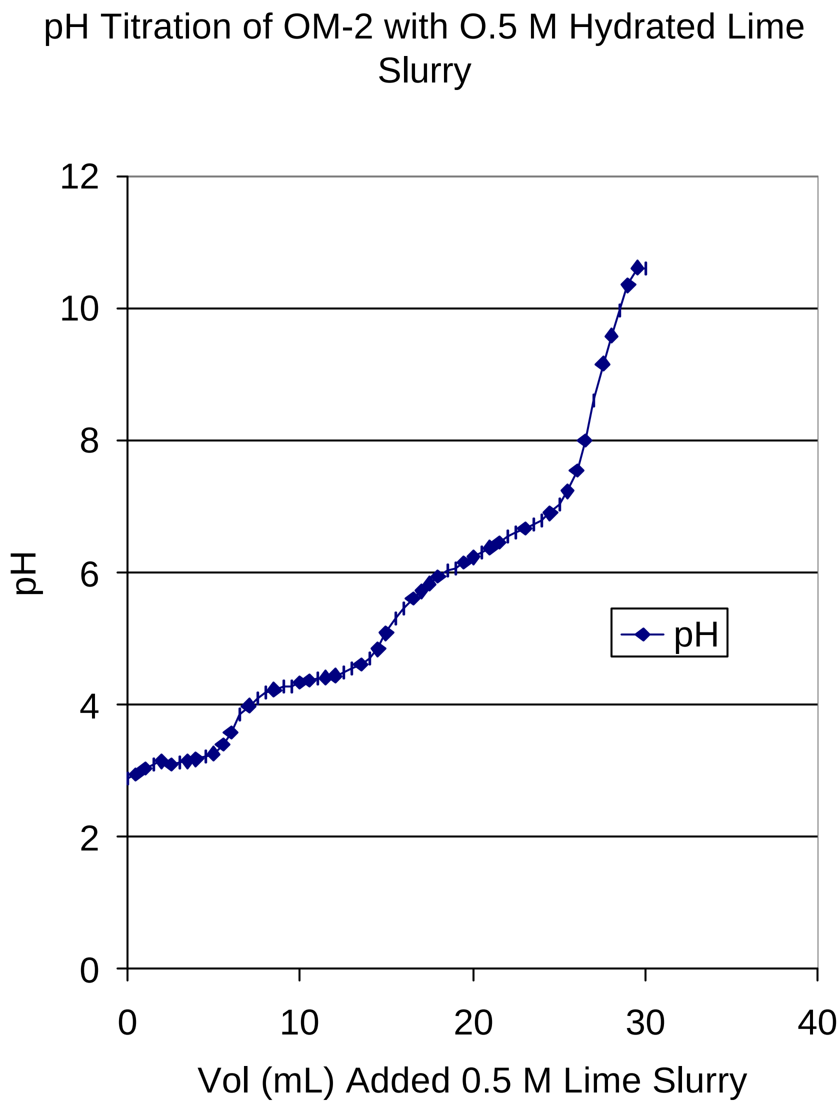

pH Titration of OM-2 with 1.0 N NaOH
12
10
8
6
4
2
0
pH
0
5
10
15
20
25
30
Vol (mL) Added 1.0 N NaOH
pH

FIG. 2



pH Titration of OM-2 with O.5 M Hydrated Lime Slurry
12
10
8
6
4
2
0
pH
0
10
20
30
40
Vol (mL) Added 0.5 M Lime Slurry
pH

FIG. 3

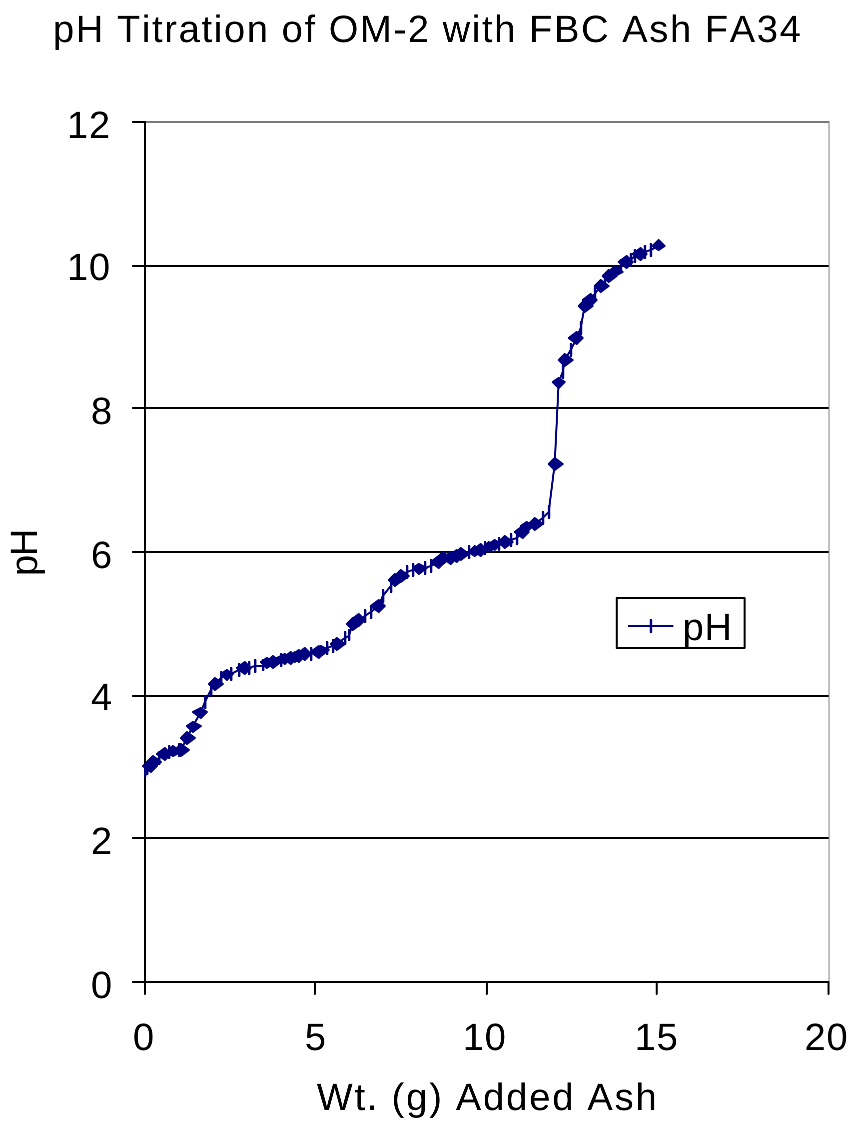
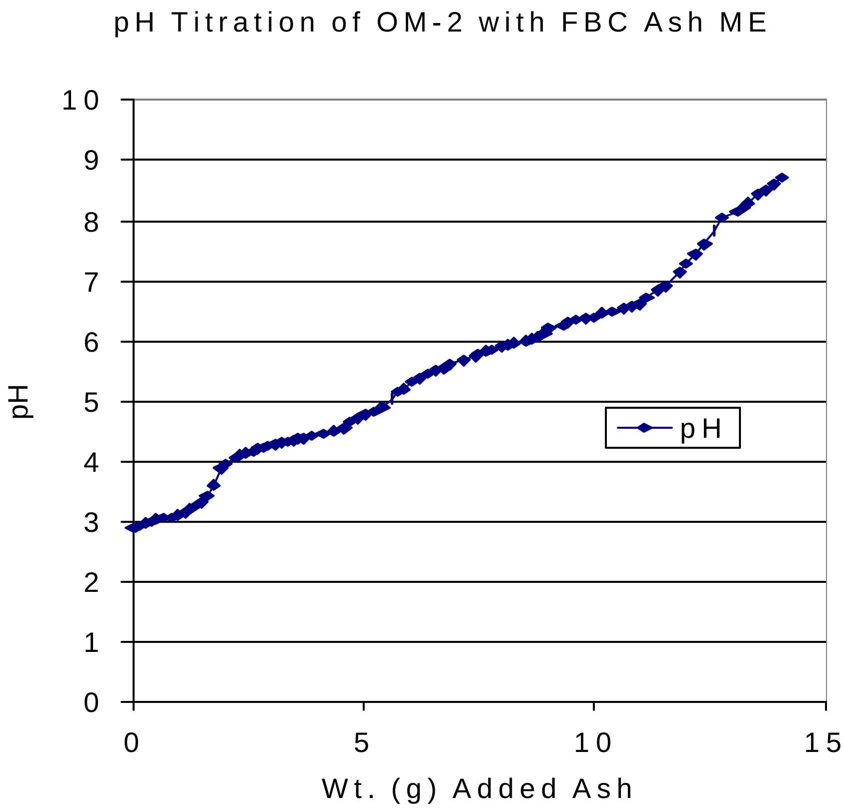
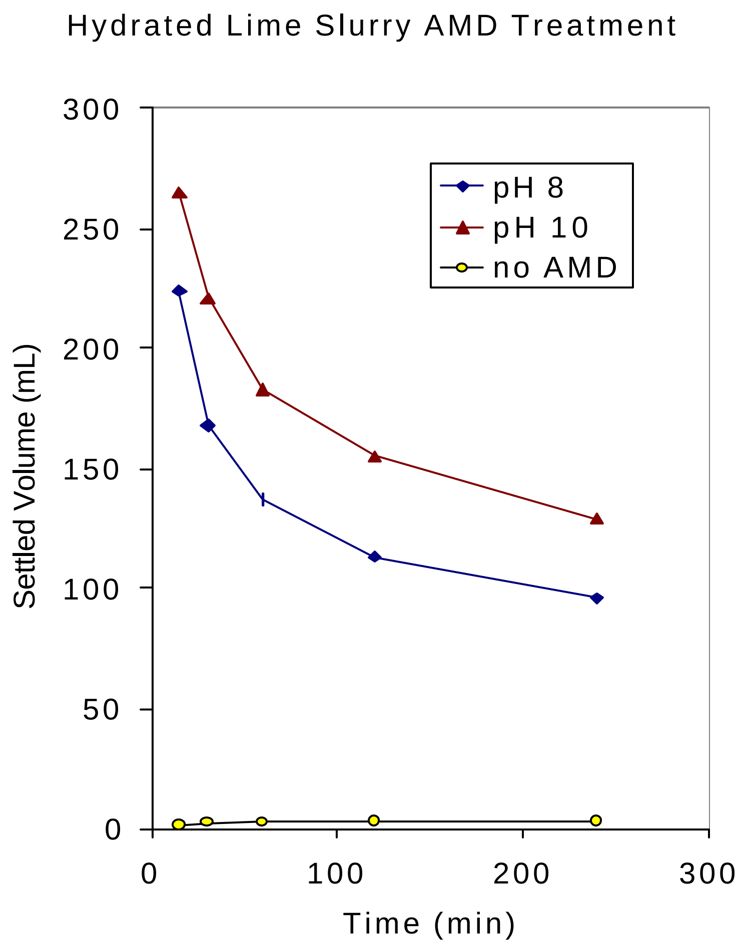

pH Titration of OM-2 with FBC Ash FA34
12
10
8
6
4
2
0
pH
0
5
10
15
20
Wt. (g) Added Ash
pH

FIG. 4



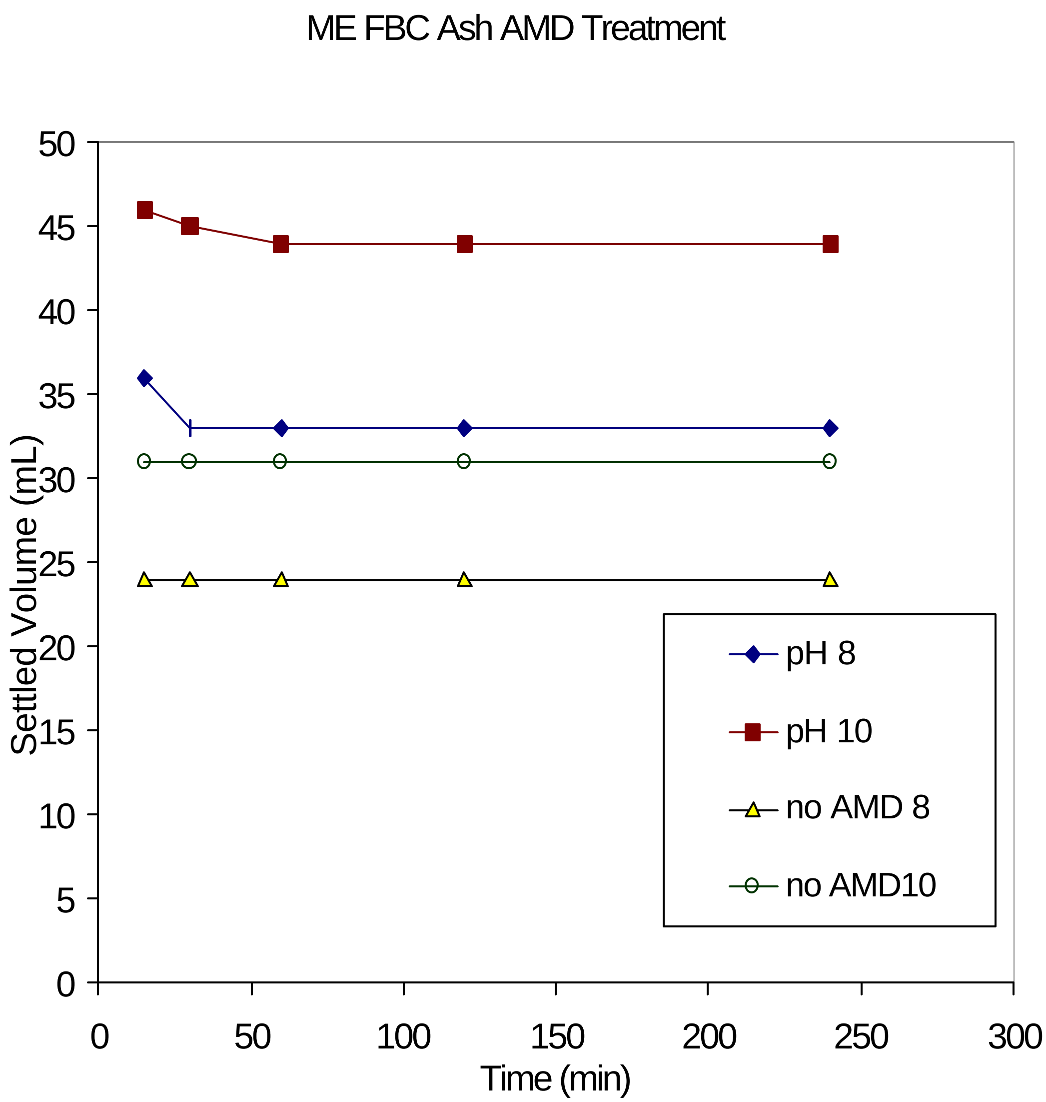
pH Titration of OM-2 with FBC Ash ME
pH
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
Wt. (g) Added Ash
pH

FIG. 5



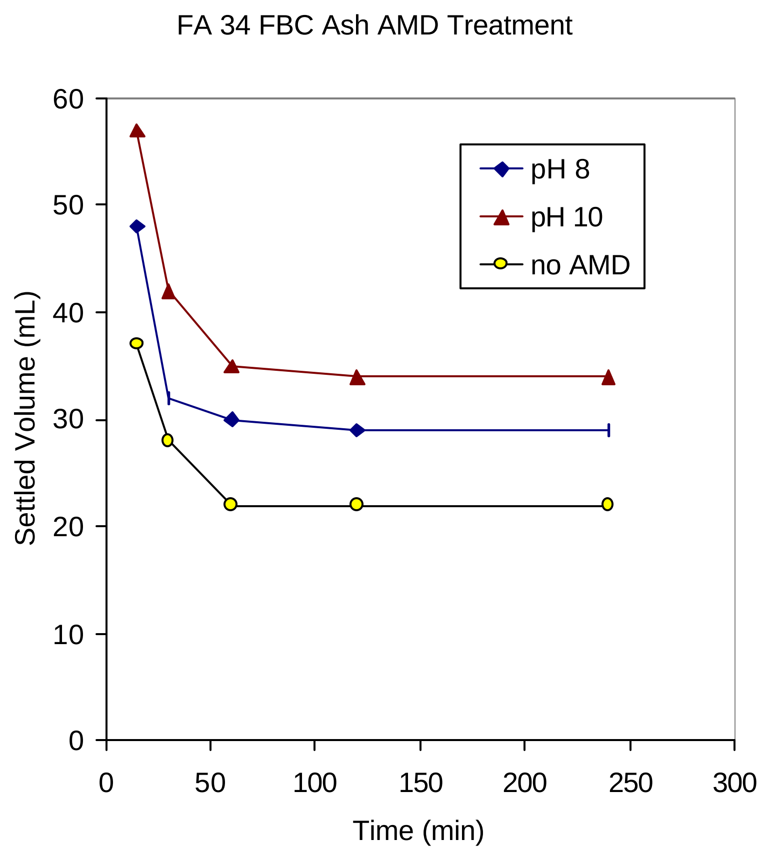
Hydrated Lime Slurry AMD Treatment
300
250
200
150
100
50
0
Settled Volume (mL)
pH 8
pH 10
no AMD
0
100
200
300
Time (min)

FIG. 6



ME FBC Ash AMD Treatment
50
45
40
35
30
25
20
15
10
5
0
Settled Volume (mL)
0
50
100
150
200
250
300
Time (min)
pH 8
pH 10
no AMD 8
no AMD10

FIG. 7



FA 34 FBC Ash AMD Treatment
60
50
40
30
20
10
0
Settled Volume (mL)
0
50
100
150
200
250
300
Time (min)
pH 8
pH 10
no AMD

FIG. 8

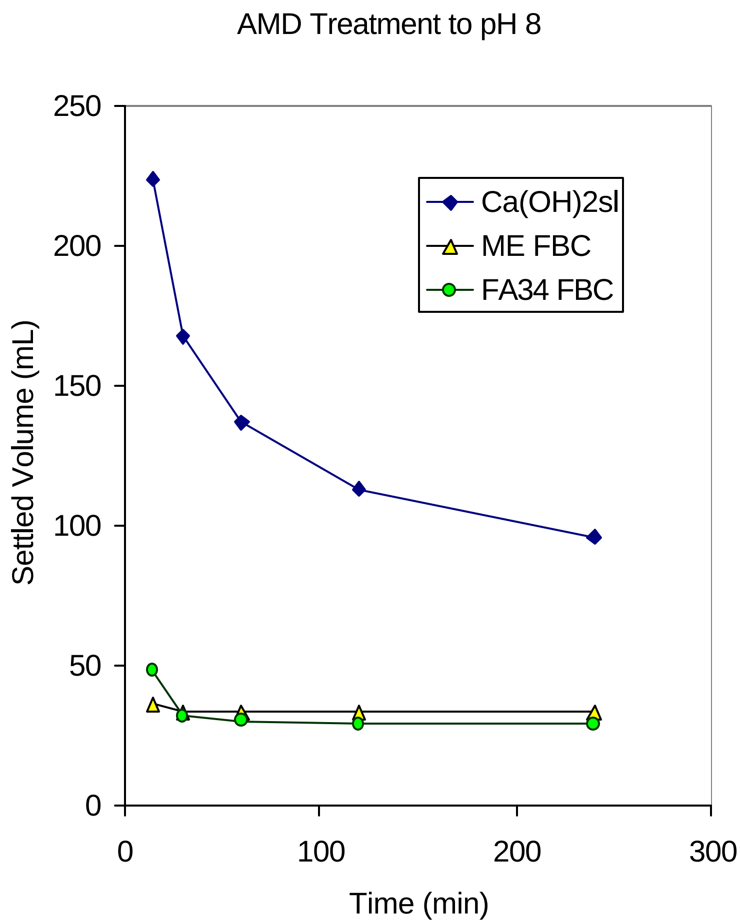
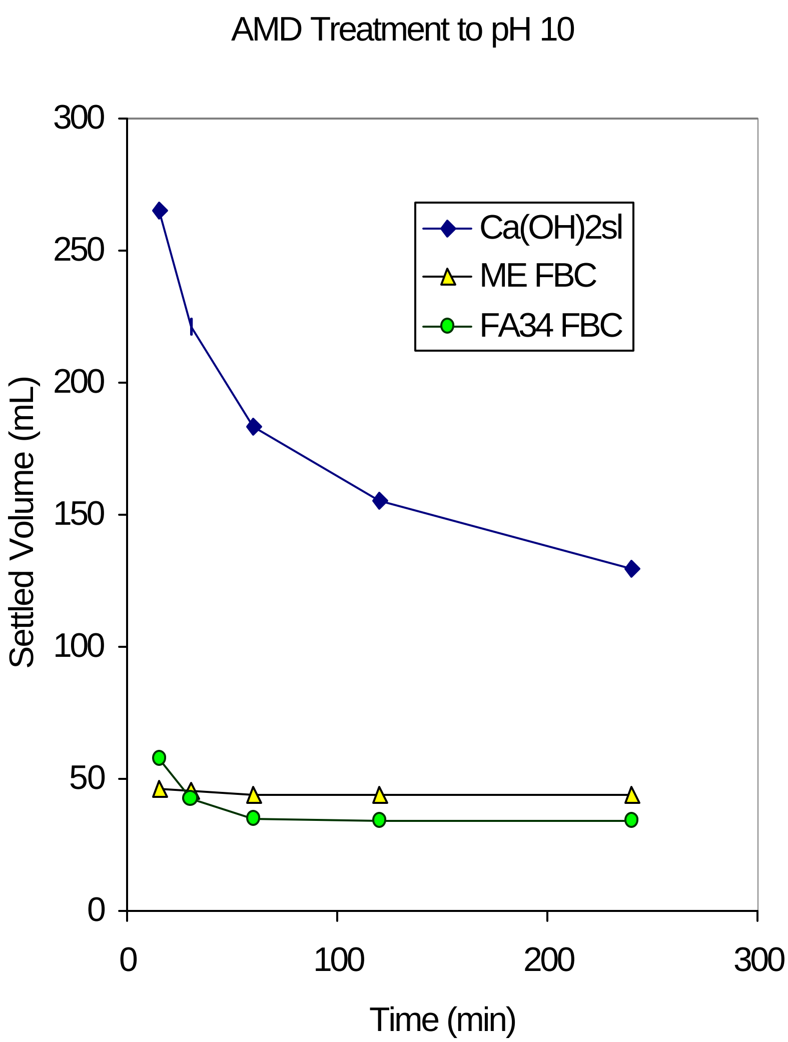
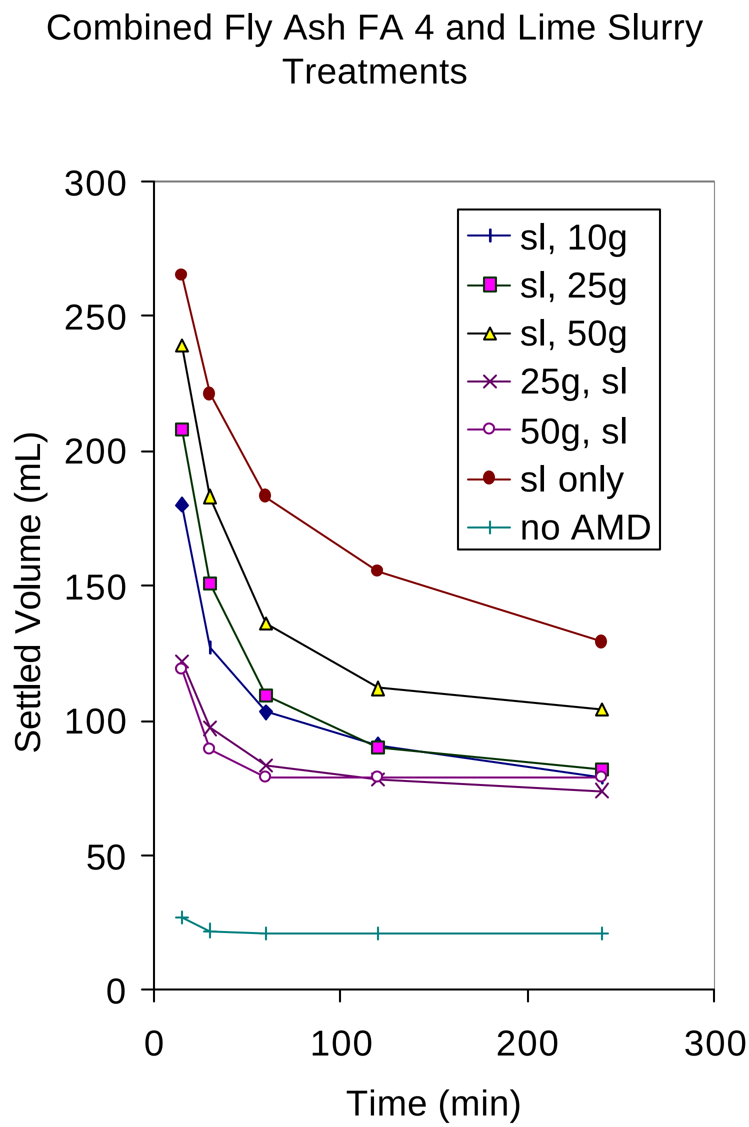

AMD Treatment to pH 8
Settled Volume (mL)
250
200
150
100
50
0
0
100
200
300
Time (min)
Ca(OH)2sl
ME FBC
FA34 FBC

FIG. 9



AMD Treatment to pH 10
Settled Volume (mL)
300
250
200
150
100
50
0
0
100
200
300
Time (min)
Ca(OH)2sl
ME FBC
FA34 FBC

FIG. 10



Combined Fly Ash FA 4 and Lime Slurry Treatments
Settled Volume (mL)
300
250
200
150
100
50
0
0
100
200
300
Time (min)
sl, 10g
sl, 25g
sl, 50g
25g, sl
50g, sl
sl only
no AMD

FIG. 11

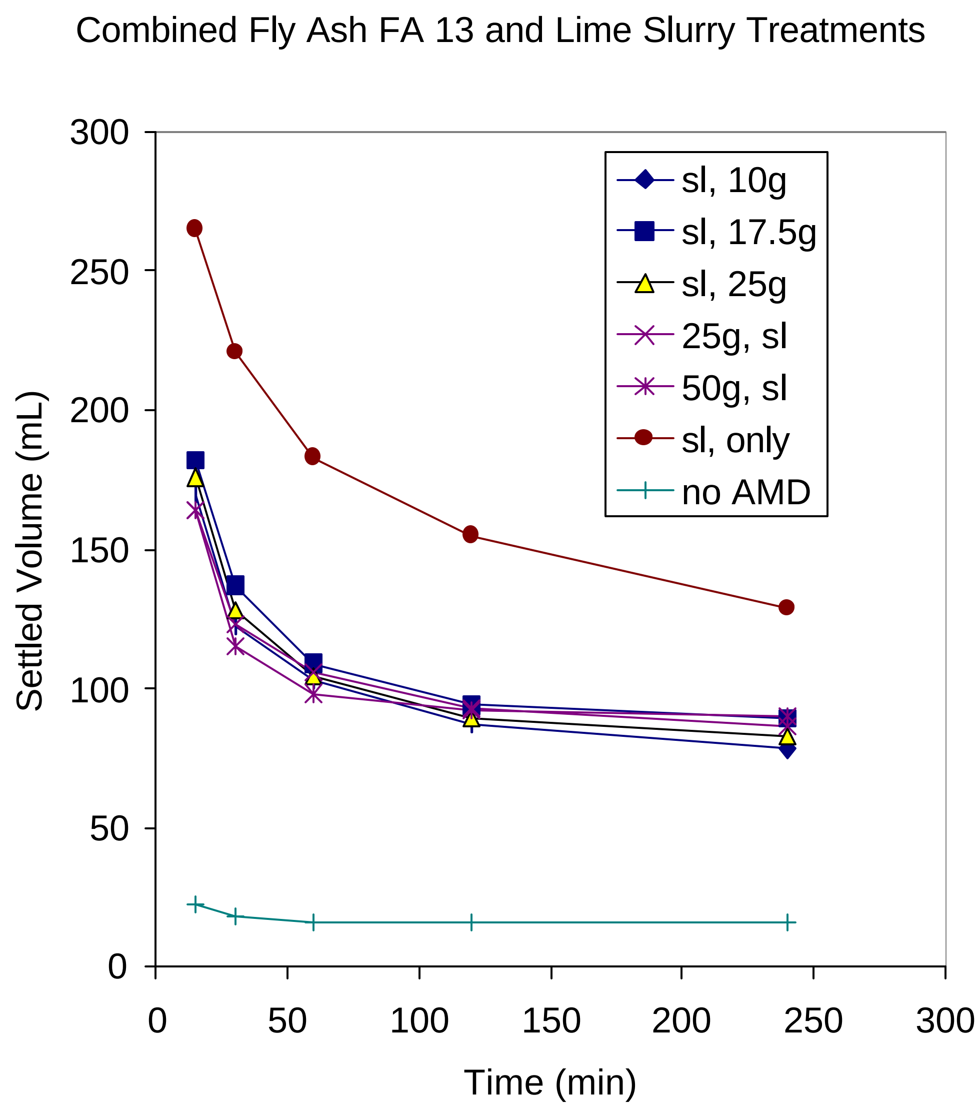

Combined Fly Ash FA 13 and Lime Slurry Treatments
Settled Volume (mL)
300
250
200
150
100
50
0
0
50
100
150
200
250
300
Time (min)
sl, 10g
sl, 17.5g
sl, 25g
25g, sl
50g, sl
sl, only
no AMD

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TABLE 1. Elemental Analysis of Ashes Used in Study

(Results in ppm)

	ME FBC Ash	FA34 FBC Ash	FA4 Fly Ash
Aluminum	66430	58490	104400
Arsenic	64.43	31.85	90.40
Antimony	<4.0	<4.0	<4.0
Barium	352.5	223.6	656.0
Beryllium	<4.0	10.98	4.96
Cadmium	4.08	10.46	7.52
Calcium	115600	110600	23480
Chromium	65.23	67.31	116.0
Cobalt	18.81	36.86	35.20
Copper	60.02	73.32	62.80
Iron	36090	95350	79200
Lead	22.17	99.76	45.60
Magnesium	5562	2596	5080
Manganese	148.5	101.8	178.0
Molybdenum	5.362	7.292	11.84
Nickel	31.13	99.76	67.20
Potassium	13610	7893	12120
Selenium	<4.0	<4.0	<4.0

Silver	<4.0	<4.0	<4.0
Sodium	2161	1546	5440
Thallium	<4.0	<4.0	<4.0
Vanadium	89.64	136.6	168.4
Zinc	72.03	106.2	104.8

TABLE 2. Synthetic AMD Composition

Metal Ion	Concentration in synthetic AMD (ppm)
Fe^{+2}	500
Fe^{+3}	250
Al^{+3}	150
Zn^{+2}	50
Mn^{+2}	50

TABLE 3. Average Concentration of Synthetic AMD Metals Found in Omega Mine Water

Metal Ion	Concentration (ppm)
Fe^{+2}	345
Fe^{+3}	256
Al^{+3}	157
Zn^{+2}	5.6
Mn^{+2}	5.6

TABLE 4. Complete Analysis of Omega Mine Water (August, 1999)

Component	Concentration (ppm)
pH	2.93
Acidity as $CaCO_3$	2520
Ferrous Iron	503.90
Ferric Iron	212.82
Calcium	343.59
Magnesium	141.44
Aluminum	181.35
Sodium	23.50
Manganese	6.41
Sulfate	3982.93
Potassium	15.26
Arsenic	<0.20
Barium	<0.02
Beryllium	0.16
Cadmium	<0.02
Cobalt	1.14
Chromium	0.10
Copper	0.07

Nickel	2.37
Lead	<0.20
Antimony	<0.20
Selenium	<0.50
Zinc	7.86

TABLE 5. Analysis of AMD from 128 Discharges throughout the U.S. The flow is in L/min: pH in standard units: conductivity in uohm/cm: all concentrations in mg/L: acidity and alkalinity in mg/L as $CaCO_3$.

Parameter	Times Reported	Mean	Median	Minimum	Maximum
Flow	49	333	67.0	5.50	3690
pH	128	2.84	3.24	1.20	7.80
Conductivity	60	2970	2125	360	27000
Alkalinity, field	8	52	28	5	153
Alkalinity, lab	128	18.2	0	0	275
Acidity	128	1500	410	270	55300
Sulfate	128	2360	1320	71	52700
Aluminum	123	88.0	27.3	0	930
Antimony	94	0.004	0	0	0.15
Arsenic	115	0.189	0	0	16.1
Barium	108	0.01	0	0	0.2
Beryllium	114	0.021	0	0	0.27
Cadmium	119	0.014	0	0	0.82
Calcium	128	183	170	6.90	483
Chloride	43	61.3	7.90	0	849

Chromium	128	0.077	0	0	7.18
Cobalt	110	0.794	0.265	0	6.0
Copper	128	0.139	0	0	2.49
Iron, Ferric	123	142	6.4	0	4106
Iron, Ferrous	120	291	69.7	0	15700
Iron, Total	128	410	96.5	0	19800
Lead	117	0.023	0	0	1.84
Magnesium	128	112	92.7	2.75	638
Manganese	128	21.9	7.45	0	164
Nickel	123	1.19	0.56	0	10
Potassium	116	4.61	3.25	0.04	47.3
Selenium	109	0	0	0	0
Silver	22	0.0005	0	0	0.01
Sodium	128	34.9	8.90	0.33	437
Vanadium	19	0.121	0.053	0	0.660
Zinc	126	4.27	0.920	0.01	146

TABLE 6. AMD Treatment Sludge Settling Volumes*

Treatment	Time (min) 15	30	60	120	240
Hydrated Lime Slurry					
To pH 8	224	168	137	113	96
To pH 10	265	221	183	155	129
No AMD (average slurry volume)	1.2	2.4	2.8	2.9	3.0
FBC Ash FA 34					
To pH 8	48	32	30	29	29
To pH 10	57	42	35	34	34
No AMD (average ash wt.)	37	28	22	22	22
FBC Ash ME					
To pH 8	36	33	33	33	33
To pH 10	46	45	44	44	44
No AMD (pH 8 wt.)	24	24	24	24	24
No AMD (pH 10 wt.)	31	31	31	31	31
Fly Ash FA 4 with Lime Slurry to pH 10					
Slurry, 10g Ash	180	127	103	91	79
Slurry, 25g Ash	208	151	109	90	82
Slurry, 50g Ash	239	183	136	112	104
25g Ash, Slurry	122	97	83	78	74
50g Ash, Slurry	119	89	79	79	79

*Average volumes of multiple runs (mL)

TABLE 7. Percent Solids in Sludges Formed by Various Neutralizing Agents

Neutralizing Agent	Average % Solids	Range of % Solids
Lime Slurry	3.75	3.33 - 4.05
ME FBC Ash	41.70	40.56 - 42.80
FA34 FBC Ash	41.05	38.99 - 43.27